A Proposed Supply Chain Risk Management Framework

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Abstract:

This paper discusses the concept of supply chain risk management (SCRM) in relation to the emerging challenges brought by globalisation and information and communication technologies (ICT) and the ability of SCRM frameworks to adapt to these latest requirements. As SCRM can be responsible for loss or gain of profit, the ultimate goal of enterprises is to have resilient supply chains with automated decision making that can deal with potential disruptions. In response to this, ICT developments such as agent based systems, decision support systems, and data mining techniques seem to be a promising solution. In this research, our aim is to analyze the existing literature on these ICT developments and SCRM systems and to observe the patterns, abilities and limitations of the existing models, in order to develop an initial SCRM framework.

Keywords: Agent based systems, data mining, decision support systems, knowledge discovery, supply chain risk management.

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1. Introduction

Increased competition in a stagnating market has led to the design of more efficient supply chains. However, it is often the case that the risks involved have not been carefully considered in an in-depth manner. Decreased stocks, longer transports and increased dependency from fewer suppliers have led to an increased vulnerability of global supply chains. Local disruptions e.g. from disasters, terrorism or simply the failure of a supplier can have severe consequences for a company and its customers all over the world (Jutna et al., 2003). According to La Londe, 1997, the actual negative outcomes of risks could be: loss of profit, late deliveries, client dissatisfaction, temporary suspension of production, damage to the business's reputation and decrease of shareholder's value. Hence, overcoming these issues is vital and for accomplishing this, businesses must adopt effective supply chain risk management (SCRM) systems that would have as an ultimate goal the prediction and identification of risks that might cause any disruptions in the supply chain as well as to perform decision making, risk mitigation and further uncertainty management.

Supply chains are becoming more and more global, networked and information centric and the volume of data and information they deal with is growing at an unprecedented rate (Enyinda et al., 2008). Efficient and effective supply chains require capturing, sharing, analyzing and managing this information and knowledge from data along the supply chain network. The existence of solutions for the aforementioned issues is mostly due to the proliferation and advancements of ICT (Giannakis & Louis, 2011) through which the developments of supply chain management (SCM) and implicitly SCRM frameworks have reached advanced stages that started from the centralized supply chain systems and reached decentralized structures in which heterogeneous entities can efficiently interact and self-mitigate, simulating thus the current globalising business requirements. In more details, the latest SCM frameworks take full advantage of the intelligent agent paradigm from ICT (Julka et al., 2002), which are being specialized for the needs of each supply chain.

Furthermore, the agent paradigm represents a very efficient tool for properly managing information towards reaching knowledge by integrating all these concepts in a decision support system based on data mining and knowledge discovery that can enhance the supply chain with a great tool for the prediction and mitigation of risks (Chatzidimitriou & Symeonidis, 2009). This paper contributes to the literature with a SCRM framework that facilitates semi-automated methods of supply chain risk identification, prediction and mitigation strategies.

To this extent, the aim of the paper is to 1) perform a literature review on SCRM, agent based systems, decision support systems and data mining for SCRM in order to identify the latest advancements and limitations of this sector, 2) propose an agent based SCRM framework and 3) explain how that framework functions. The proposed model will facilitate the decision making in the supply chain through the following multiple capabilities:

- Access to past experiences and operational data to analyze the changes as they occur in the global supply chain and where necessary provide the corresponding response for potential risks.
- Incorporating the learning, knowledge sharing and knowledge reuse element in the DSS for supply chain risk management.
- Semi-automated knowledge creation, updating and retrieving capability.
- Capturing implicit knowledge and transforming it into explicit knowledge.
- Consolidating the knowledge, if necessary transforming the identified patterns and/or models to alternative representations.

The remainder of this paper is structured as follows: section two is concerned with the literature review of SCRM frameworks, agent based systems, decision support systems and data mining. This section presents the advancements and limitations/gaps of research in this sector as well as it describes certain concept design criteria. Consequently, section three presents the proposed SCRM framework and its functioning. Furthermore, the conclusion/discussion section reiterates the main findings of this study and the main assets of the proposed model. Finally, further research suggestions are made.

2. Literature Review

2.1 Risks and Supply Chain Risk Management (SCRM) frameworks

Supply chain risk vulnerability is a real issue in today's businesses and SCRM is still underestimated which can lead to severe disruptions that according to (Jutna et al., 2003) can cause severe business loss. In response to this, the literature debate is very wide and provides the industry with a plethora of possible solutions to overcome the aforementioned issues. When it comes to defining the term "Supply Chain (SC) risk", there are many possible interpretations and variations. To this extent, (March & Shapira, 1987) define "SC risk" as: "the variation in the distribution of possible supply chain outcomes, their likelihood and their subjective values", whereas (La Londe, 1997) focuses on risk outcomes: "these uncertain variations that affect the flow of information, materials or products across organization borders".

In order to counteract these risks, proper SCRM frameworks must be implemented. According to (Jutna et al., 2003), there are four main directions that define an effective SCRM framework: SC risk sources, risk consequences, risk drivers and risk mitigating strategies. Regarding risk sources, (Jutna et al., 2003) identify three categories: environmental, network and organizational. Another classification of risks that impact on the SCRM framework's structure which is described by (Shaohua, 2008 and Zsidisin, 2003) refers to endogenous (interactions among the partners within the supply chain) and exogenous risks (interactions between the supply chain and its environment which is not controllable). In relation to risk consequences, they are perceived by (Goldberg et al., 1999 and Harland & Branchley, 2001) as non lucrative outcomes, safety concerns and damage to reputation. Regarding risk drivers, (Jutna et al., 2003 and Enyinda et al., 2008) present five main triggers: focus on efficiency rather than effectiveness, globalisation of SC, centralized distribution, outsourcing and the reduction of the supplier base whereas mitigation can be achieved, according to (Miller, 1992), through four strategies: control, avoidance, flexibility and cooperation. On another approach, (Meydanoglu, 2009 and Bandyopadhyay, 1999) view SCRM as: 1) risk identification, 2) risk analysis, 3) risk reduction, transfer and acceptance and 4) risk monitoring.

Finally, some general SCRM frameworks for practical usage and simulation are: the multi-objective model investigated by (You et al., 2009), the predictive control model by (Puigjaner, 2008), the SCEM model developed by (Meydanoglu, 2009), the agent based model described by (Adhitya et al., 2007), the SCOR model (SC Operations Reference) belonging to SCOR, 2008), the spreadsheet-based simulation proposed by (Shaohua, 2008), the discrete event simulation, system dynamics and Petri-nets presented by (Jahangirian et al., 2010). Furthermore, several approaches to risk management in the petroleum and chemical industry are proposed by (Julka et al., 2002) and (Tah & Carr, 2001) proposes an object oriented model for the construction supply chain. Despite the existence of these solutions, the literature still has a major gap: the absence of a general SCRM framework configuration which can self-adapt to the needs of each business and which can easily bind to the past experiences encountered in the global supply chain in order to be able to deal with risks. Furthermore, the actual risk concept is not entirely defined due to the existence of many risk categorisations without proper mitigation strategy. Thus, further research in this sector is still needed. Finally, from the wide varieties of SCRM frameworks, the focus of this study will now be centred on agent based systems and the developments in this field.

2.2 Agent Based Systems

According to (Wooldrige & Jennings, 2005), an agent is a system/entity that operates without the direct intervention of humans and has certain control over its action and internal state as well as the ability to interact with other agents; this agent reacts according to the environment in which it operates but also to its goals.

Usually, agents operate within multi-agent based systems (MAS) in which autonomous entities collaborate and play different well established roles through specific protocols defined by the structure of each MAS (Zambonelli et al., 2000). Furthermore, the collaboration/interaction among agents is perceived by (Zambonelli et al., 2000) to be strictly related to each agent’s role and it is usually done through message passing. As these agents deploy collaboration, intelligence and mobility, they are very useful in supply chains (Julka et al., 2002). According to (Bond &

Gasser, 1988), since supply chain management (SCM) is concerned with the coordination among its (semi)autonomous entities, multi-agent computational environments are the most suitable for designing effective frameworks in this sector. Moreover, multi-agent environments in SCM are perceived by (Moyaux et al., 2006 and Verdicchio & Colombetti, 2002) to allow efficient interaction in decentralized environments as well as emergent and concurrent actions which are the most observed patterns in the latest SCM sector behaviour.

As there are no general agent-based systems, but rather customized ones for each business, the design choices must take into consideration multiple factors. A general agent decomposition structure is proposed by (Fox et al., 2000) which recommend the existence of variations of the following agents: order acquisition agent, logistics agent, transportation agent, scheduling agent, resource agent and dispatching agent. The interaction among these agents in a decentralized SC is done in a mash like fashion rather than star-wise, meaning that each agent can interact with any other agent without an intermediary. To this extent, the existing literature presents several agent-based models/systems for SCRM that try to achieve maximum potential by counteracting or mitigating risk factors and by exploiting the most efficient paths/interactions. The following table presents the taxonomy of several frameworks:

Table 1 Agent Based SCM and SCRM frameworks

Agent	**Observations**	**Source(s)**
Agent Facilitated Model	• Enhanced delivery services, reduced costs and potential risk avoidance. • Product quality and other is not taken into consideration.	(Zeng & Sycara, 1999)
OO Agent based framework	• Monitoring, modelling and management of SC.	(Julka et al., 2002)
Self correcting architecture	• Automatic selection of best techniques and suppliers.	(Kumar & Mishra, 2011)
Multi-agent based framework for	• Handles risks from all the nodes of the SC	(Giannakis & Louis, 2011)

SCRM		
Other general agent based SCM frameworks	(Barbuceanu et al., 1997), (Chen et al., 1999), (Sadeh et al., 1999), (Ahn & Park, 2003), (Fu et al., 2000), (Lin et al., 2005)	

Concluding from the previous analysis, the literature provides ample opportunities for general SCM rather than for SCRM. The reason for this is that the main focus is set on rising the overall supply chain efficiency that would potentially lead to profit, as a traditional business approach, disregarding the risk management sector. This is a major gap in the literature because in the current globalized and dynamic environment, risks are inevitable and thus, the same priority (or higher) should be given to risk management as it is given to other sectors of a supply chain. Moreover, if a supply chain is to be resilient and well-prepared to deal with risks in the global markets, it requires accurate, current and understandable knowledge about different partners, current status of its work and operations. To this extent, the need for agent based SCRM frameworks is vital as their collaborative properties totally bind on the current supply chain requirements. Furthermore, this knowledge must be trustworthy and therefore it is also vitally important that the enterprises also understand the levels of reliability, uncertainty and risk that exist within the available knowledge. Knowledge discovery and sharing can promote the development of a high level “supply chain intelligence” pertaining to the identification, analysis and evaluation of risks in the supply chain. Knowledge management can facilitate supply chain collaborative learning and the development of knowledge about risk. These prompted the need of knowledge based tools and techniques for supply chain risk management. These actual tools that take advantage of knowledge are the decision support systems which use this resource to make informed decisions concerning the supply chain behaviour.

2.3 Decision Support Systems (DSS)

According to (Zarandi & Zarandi, 2008), DSSs are interactive software-based systems used for information compiling [(that take advantage of data mining and knowledge and data discovery (Piramuthu, 2005))] with the ultimate goal of reaching a decision for a specific purpose. One of the possible decisions that could be necessary is the one of overcoming uncertainty and disruptions in the SC as agreed by (Bansal et al., 2005), as well as other decisions that the entire SCM sector requires as stated by (Xia & Chen, 2011). The structure of a DSS can vary as each DSS must be specialized (Piramuthu, 2005) to incorporate the business rules of each entity that uses it.

Initially, according to (Fox et al., 2000) there are five main issues that must be considered when developing a DSS: distribution of SC activities among agents, coordination, responsiveness to the interacting environment, interface with the interacting modules and reusability. From another point of view, (Goodwin et al., 1999) identify two main categories of potential DSS drivers: information exchange and building an integrated catalogue. Furthermore, (Xia & Chen, 2011) mention the fact that due to the dynamic nature of a SC risk system, the DSS must reflect the interaction and relationship among risk managerial factors and elements. Moreover, apart from the dynamic structure of the SC, according to (Biswas & Narahari, 2004), the focus should be set on three other factors that contribute to the DSS design: large scale/complexity of supply chains, hierarchical structure of decisions and asynchrony of various inputs.

Overall, the main technical function of a DSS is the progressive transformation of data into information and knowledge, which at the end, will be used for all the previously mentioned functions (Louw, 2006).

When it comes to reviewing the current literature on DSS, a categorisation that is provided by (Meixell & Gargeya, 2005 and Muckstadt et al., 2001) distinguishes the following models: MRP models, Mathematical Programming-Based Models, Inventory models and APS systems. Based on the previously mentioned models, (Muckstadt et al., 2001) argues that they are not consistent and proposes a model created on five main principles – the No B/C Strategy. Additionally, (Stadtler & Kilger, 2008) provide a thorough overview of the developments of DSS, comprising practices from 1970-2002 into a sound work. Finally, as a response to the current requirements, most of the existing DSSs are agent based, taking full advantage of this ICT paradigm. The following table presents several DSS and their characteristics.

Table 2 Decision Support Systems for SCM and SCRM

DSS Description	**Source**
• Handles risks from all the nodes of the SC. • A further improvement: adaptation to support forecast-based SC.	(Giannakis & Louis, 2011)

• The ability to handle a wide variety of disruptions however. No robustness.	(Bansal et al., 2005)
• Focuses on strategic, tactical and operational decision making in SC. • Allows problem formulation at different levels of abstraction.	(Biswas & Narahari, 2004)
• Aims to shrink the SC uncertainty circle which will give certain leverage to a business.	(Mason-Jones & Towill, 1998)
• Other DSSs for general SCM purposes	(Goodwin et al., 1999), (Piramuthu, 2005), (Xia & Chen, 2011), (Lendermann et al., 2003), (Zarandi & Zarandi, 2008), (Kumar & Agrawal, 2011), (Julka et al., 2003)

As it can be seen, the literature provides sufficient examples of the DSSs usage in the field of SCM however the use of DSSs for SCRM is still limited possibly due to the lack of importance accorded to this sector. However, the incorporation of a DSS in the SCRM system is vital in order to deal with the latest global challenges. Specifically, by (re)using knowledge within the DSS, identifying patterns, learning and consolidating that knowledge, the DSS could provide sound decisions that can definitely benefit the SCRM.

Finally, these decision support systems provide informed advice based on data manipulation and more specifically based on data mining which is used to make the transition from irrelevant data towards useful knowledge.

2.4 Data Mining

Due to the proliferation of ICT, the amount of the available data that today's businesses operate on has increased dramatically and the task of identifying the most appropriate and useful information for a specific purpose has become a challenge. To this end, the use of data mining (the application of algorithms for extracting specific patterns from data) is vital. Generally, according to (Chatzidimitriou & Symeonidis, 2009), data mining has proven to be very useful in SCM in dealing with aspects such as: market analysis, inventory scheduling and customer and supplier categorisation. Furthermore, several benefits of DM's application in SCM are abnormality detection and potential market opportunities identification which can be valuable assets for forecasting and pricing policy. Another critical aspect of DM usefulness is the inventory control (Mileff et al.,

2006) for which (Thotappa & Ravindranath, 2010) propose an efficient model of cost reduction. In the same context, (Singh & Raisinghani, 2001) argue that DM can enhance the match between supply and demand which would result in the reduction or at best, to the elimination of stocks. Furthermore, (Kusiak & Smith, 2007) argue that DM plays an increasing role in innovation and especially in product design and production systems.

However, since one of the challenges of SCM is to achieve coherence among heterogeneous globally distributed decision makers / agents (Wu et al., 2000), the multi-agent framework is one of the most famous application fields for data mining concerning SCM. To this extent, intelligent agent frameworks such as Mertacor (Chatzidimitriou & Symeonidis, 2009) or CIMS with DM (Zhong et al., 2002) have been developed. In the same context of collaborative agents, the B2B-SC model proposed by (Holimchayachotikul et al., 2010) is a very useful tool for performance measurement achieved by focusing on relationship rules of the collaborative performance attribute. Another application of DM in the collaborative structure of SCM is described by (Fliedner, 2006) through their elaborated framework for supply chain forecasting in which DM is used as a tool to detect trends and to overcome several barriers to supply chain prediction opportunities.

As it can be seen, DM is widely used in SCM, mostly for optimisation and forecasting aspects. However, a limitation of the current literature is the absence of debate in the field of DM for SCRM and more specifically, the absence of the relation between DM and DSSs for SCRM and in order to fully take advantage of the latest ICT developments, DM must definitely be used within a SCRM framework, especially due to the large amount of existing information. Having this context, contributing to the literature with a new SCRM framework that aims to solve certain issues is required.

3. The proposed framework

The proposed multi-agent SCRM framework aims to simulate the structure of an effective supply chain that incorporates a DSS for risk management. In order to assure full communication capabilities among the partners from the supply chain, the agent system is decentralized and each agent can communicate with any other entity from the SC through the network. The main components of the framework are the agents that perform the main functions of the supply chain and the DSS which is viewed as a more complex generic agent/module. Each agent will be presented individually:

Forecasting agent
The forecasting agent is used for a dual purpose. The first one is to generate scenarios for future supply chain working environments (prices, new technologies, new partners, business goals assurance, and market opportunities/weaknesses). The second one is to foresee potential risks in all the possible configurations/scenarios and to send those scenarios to the risk DSS module in order to find a suitable solution and to update the risk database. Thus, in the case that a scenario actually happens, a solution would exist or at least, the system would have certain knowledge to generate a solution.

Corporate Strategy Agent
This agent deals with all the business goals, main strategies and constraints that the supply chain must accomplish. The purpose of this agent's existence is that, by being an autonomous entity within the SC it can easily be updated and thus, all the other agents would have access to the latest requirements. Moreover, this agent has a decisive role in any decision making process as only if the desired performance is reached, a specific decision can be taken. Hence, the scheduling and optimisation agent will work closely with the corporate strategy agent and as well as with the DSS module for risk management.

Scheduling and Optimisation agent
This agent is responsible for all the needed scheduling and optimisation within the supply chain. Basically, this agent performs complex computations to find the most efficient and flexible scheduling configurations. Also this agent deals with transport issues based on the derived schedules. Furthermore this agent also performs certain logistic tasks by dealing with suppliers and other supply chain partners (this is done in close interaction with the production agent).

Learning agent
This agent manages all the information from the supply chain and constantly updates the knowledge and data base of the SC. This aspect is vital for being able to assure a suitable scheduling and optimisation that both guarantee the fulfilment of the business goals. The actual "learning" is represented by the patterns that are encountered at the processes and events that happen in the SC. Moreover, as previously described by (Kumar & Mishra, 2011), the learning agent should be capable of learning

both dynamically (through active processes) and statically through the existing knowledge from the database. This way, more appropriate and informed decisions can be taken.

Dispatching agent
This agent based on the work of (Fox et al., 2000) is responsible for the order release and for the execution of the schedule instructions imposed by the scheduling agent. Furthermore, in case of schedule irregularities, this agent communicates with the scheduling agent to refractor the orders. It may also take certain decisions based on the encountered context and accordingly to the optimisation goals.

Inventory agent
This agent is responsible for managing the inventory items by keeping track of their relevant information and interacts with the dispatching and production agents in order to maintain updated information. An additional functionality of this agent is proposed by (Kumar & Mishra, 2011) and consists of certain storage economy capabilities.

Production agent
The production agent is responsible for assuring minimum manufacturing cost and also for the coordination/interaction of the supply chain partners during the supply, manufacturing and delivery of the products. This agent is vital especially for the global supply chains where the components that build a product come from different areas, and thus, effective coordination is need in order to assure maximum outcomes.

Inter-business communication agent
This agent has a strategic role for gaining competitive advantage and for offering the SC certain back-up solutions in case of unexpected but also foreseen issues. Its main purpose is to keep track of other businesses that might prove useful to collaborate with and which could offer back-up solutions in case of intra-SC partner failure. Basically, this agent can be seen as a repository manager of potential SC partners.

Risk / KPI monitor agent
This agent has the responsibility of identifying potential risk situations. The identification is done by constantly communicating with all the agents involved in the supply chain as each other agent is liable for generating or encountering a type of risk. The actual identification is done by monitoring key performance indicators as described by (Bansal et al., 2005) and when

a specific risk situation is identified, the problem is passed to the generic risk handler agent in order for a solution to be generated.

The generic risk handler agent / The risk DSS module

This agent can be viewed as an entire module due to its complexity as it involves integrated functionalities, three subagents and an independent database. When this generic risk handler agent receives a solution request for a risk from either the Risk/KPI monitor agent or the Forecasting agent, the following steps are followed:

1. The request is passed to the Risk Processing Coordination sub-Agent (RPCA) which accesses the Solution Generation Agent (SGA).

2. The SGA assesses the risk and checks whether the risk database contains a similar or previously encountered type of risk for which a solution exists.

3. If a solution for that risk exists in the DB, then step 5 is executed.

4. If a solution does not exist in the database, then the SGA generates a mitigation strategy by asking the RPCA to access the SC database and retrieve the specific data or knowledge needed for generating a solution.

5. When a solution is reached (either existing one or newly generated one) the Solution Assessment sub-Agent (SAA) is requested.

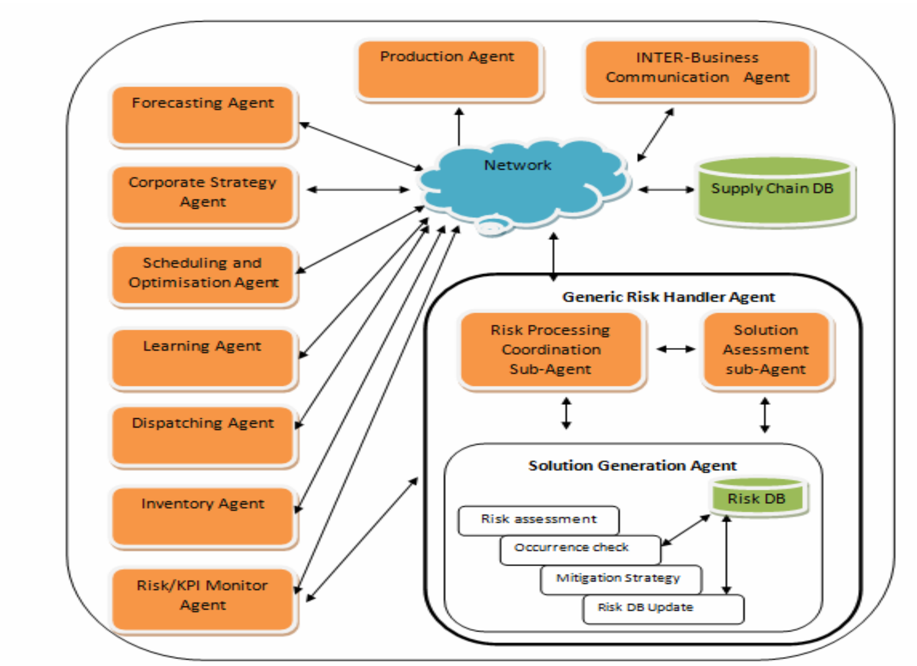
6. The SAA requests the RPCA to check with the Corporate Strategy Agent and with the Scheduling and Optimisation Agent whether the proposed solution is in accordance with the business goals and if it is feasible to implement in the current context.

7. If the solution is not feasible, then step 4 is executed.

8. If the solution is feasible, then RPCA requests the SAA to update the risk database with that solution.

Furthermore, as it is very hard in complex systems to define a good solution, a performance range would be very useful to implement. And thus, this DSS could generate many solutions in that range and the final decision (if it is a critical situation) can be either left to the manager or a more advanced solution performance analysis can be performed. To this extent for future extensions of the performance measurements, the need of the SAA is vital. Finally, the inter-agent collaboration/interaction protocols will be done through message passing in which knowledge will be exchanged. However, further research needs to be done in this direction.

Fig 1 The proposed framework



Conclusion

Overall, the importance of SCRM in the global environment has been constantly increasing becoming lately a vital part of supply chain management as it is directly responsible for gain or loss of profit. Firstly, the literature shows that the advancements in SCRM frameworks have been binding on the emerging ICT techniques (agent systems, data mining, knowledge management, decision support systems, etc). Secondly, it has been noticed that the existing SCRM frameworks are not general-purpose, being rather specialized for the needs of each business. Thirdly, nowadays' the global industry is striving to request highly efficient SCRM systems that can deal with very large amounts of data and especially with real-time data in order to provide informed advice about the decisions to be taken in these highly dynamic and decentralized environments in which risks are unavoidable. In response to all these, this paper proposed a SCRM framework that has an incorporated and highly modular knowledge based

DSS that allows efficient incorporation of patterns and risk avoidance solutions, complying in the same time with the business rules in order to provide efficient decisions. Furthermore, the proposed model uses past experiences from the global supply chain as well incorporates learning capabilities, knowledge sharing, knowledge reuse and consolidation through transforming the identified patterns, capturing thus implicit knowledge which leads to explicit knowledge – an aspect which is perceived to be vital for SCRM.

Future Research

The current paper is the initial part of a broader study concerning supply chain risk management. The next steps of the project include: further research on potential risks and risk sources and the provision of specialized and optimized solutions for several types of those identified risks, testing and adapting the proposed model, development of UML diagrams for the revised model, review of the best agent interaction models and their limitations, identification of the best technologies for real-time risk pattern detection based on manufacturing data, identification of the best model implementation environments, model implementation, testing with real data, research on the effects of emerging technologies on the transformation of SCRM and provision of extension opportunities for those emerging technologies and issues. The actual development will start by describing the agents using Unified Modelling Language, which will actually represent programming implementation classes and all inter-agent communication, will be done through relationships among classes and message passing. Furthermore, for the implementation of the DSS, specific logic techniques will be deployed in order to simulate pattern-recognition and learning capabilities. All the data that the system will deal with will be stored in a relational database with multiple access layers. Finally, all these modules will be integrated in a web based application.

References

Adhitya, A, Srinivasan R, and Karimi I A. (2007). Heuristic rescheduling of crude oil operations to manage abnormal supply chain events, *American Institute of Chemical Engineers Journal*, Vol. 53, No. 2, pp. 397-422.

Ahn, H J and Park, S J. (2003). Modeling of a Multi-agent System for Coordination of Supply Chains with complexity and Uncertainty, in eds. Lee, J and Barley, M, *PRIMA 2003,* pp.13-24.Springer, Berlin.

Bandyopadhyay, K, Mykytyn, P and Mykytyn, K. (1999). A framework for Integrated Risk Management in Information Technology, *Management Decision*, Vol. 37 No. 5, pp. 437-44.

Bansal, M, Adhitya, A, Srinivasan, R, and Karimi, I A. (2005). An Online Decision Support Framework for Managing Abnormal Supply Chain Events, *European Symposium on Computer Aided Process Engineering – 15*, pp. 985 – 991.

Barbuceanu, M, Rune, T and Fox, M S. (1997). Agent Based Design and Simulation of Supply Chains, *WETICE 1997*, pp. 36-42.

Biswas, S and Narahari, Y. (2004). Object Oriented Modelling and Decision Support for Supply Chains, *European Journal of Operational Research*, Vol. 153, pp. 704—726.

Bond, A H, & Gasser, L. (1988). An analysis of problems and research in DAI, *Readings in distributed artificial intelligence*, pp. 3-35.

Chatzidimitriou, K and Symeonidis, A. (2009). Agents in dynamic Supply Chain Management environments: Data mining-driven design choices, *Intelligent Systems*, Vol. 24, pp. 54—63.

Chen, Y, Peng, Y, Finin, T, Labrou, Y, Cost, S, Chuc, B, Yaoc, J, Sun, R and Wilhelm, B. (1999). A negotiation-based Multi-agent System for Supply Chain Management, *Proceedings of Agents 99 Workshop on Agent Based Decision-Support for Managing the Internet-Enabled Supply-Chain*, pp. 15—20.

Enyinda, C I, Ogbuehi, A and Briggs, C. (2008). Global Supply Chain Risks Management: A New Battleground for Gaining Competitive Advantage**,** *Proceedings of ASBBS*, Vol. 15 No 1.

Fliedner, G. (2006). Collaborative Supply Chain Forecasting: A Lean Framework, *Alliance Journal of Business Research*, Vol. 2.

Fox, M S, Barbuceanu, M and Teigen, R. (2000). Agent-Oriented Supply-Chain Management, *The International Journal of Flexible Manufacturing Systems*, Vol. 12, pp. 165–188.

Fu, Y, Piplani, R, de Souza, R and Wu, J. (2000). Multi-agent enabled modelling and simulation towards collaborative inventory management in

Supply Chains, *Proceedings of the 2000 Winter Simulation Conference*, Vol. 10-13, pp. 1763 –1771.

Giannakis, M and Louis, M. (2011). A multi-agent based framework for supply chain risk management, *Journal of Purchasing & Supply Management*, Vol. 17, pp. 23–31.

Goldberg, S, Davis, S & Pegalis, A. (1999). Y2K risk management, New York, Wiley.

Goodwin, R, Keskinocak, P, Murthy, S, Wu, F and Akkiraju, R. (1999). Intelligent Decision Support for the e-Supply Chain, *American Association for Artificial Intelligence*, pp. 76-81.

Harland, C and Branchley, R. (2001). Risk in supply networks, *Proceedings of the European Operations Management Association 8th Annual Conference*, pp. 306-318.

Holimchayachotikul P, Derrouiche, R, Leksakul, K and Guizzi, G. (2010). B2B Supply Chain Performance Enhancement Road Map Using Data Mining Techniques, *9th WSEAS International Conference on SYSTEM SCIENCE and SIMULATION in ENGINEERING (ICOSSSE'10).*

Jahangirian M, Eldabi, T. (2010). Simulation in Manufacturing and Business: A review, *European Journal of Operational Research*, No. 203, pp. 1-13.

Julka, N, Srinivasan, R and Karimi, I. (2002). Agent-based supply chain management: Framework, *Computers and Chemical Engineering*, Vol. 26, pp. 1755-1769.

Kumar, V and Mishra, N. (2011). A Multi-Agent Self Correcting Architecture for Distributed Manufacturing Supply Chain, *IEEE Systems Journal*, Vol. 5, No. 1.

Kumar, S and Agrawal, S. (2011). GIS as a decision support for supply chain management, *Geospatial World Forum*, India 2011.

Kusiak, A and Smith, M. (2007). Data mining in design of products and production systems, *Annual Reviews in Control*, Vol. 31, pp. 147–156.

La Londe, B. (1997). Supply chain management: myth or reality?, *Supply Chain Management Review*, Vol. 1, pp. 6-7.

Lendermann, P, Julka, N, Gan, B P, Chen, D, McGinnis, L F and McGinnis, J P. (2003). Distributed Supply Chain Simulation as a Decision Support Tool for the Semiconductor Industry, *SIMULATION*, No 79, pp. 126.

Louw J. (2006). Advanced supply Chain Planning Processes and decision support systems for large scale petrochemical companies, *PhD Dissertation*.

March, J and Shapira, Z. (1987). Managerial perspectives on risk and risk taking, *Management Science*, Vol. 33(11), pp. 1404-1418.

Mason-Jones, R and Towill, D. (1998). Shrinking the supply chain uncertainty circle, *IOM Control Magazine,* Vol. 24 (7), pp. 17-22.

Meydanoğlu, S E B. (2009). The role of supply chain event management systems for supply chain risk management, *European and Mediterranean Conference on Information Systems 2009.*

Meixell, M and Gargeya, V B. (2005). Global supply chain design: A literature review and critique, *Transportation Research Part E 41*, pp.531–550.

Mileff, P and Nehéz, K. (2006). A new inventory control method for supply chain management, *12th International Conference on Machine Design and Production*,

Moyaux, T, Chaib, B and D'Amours, S. (2006). Supply Chain Management and Multiagent Systems: An Overview, *Multiagent-Based Supply Chain Management*, pp. 1-27.

Muckstadt, J, Murray, D and Collins, D. (2001). Guidelines for Collaborative Supply Chain System Design and Operation, *Information Systems Frontiers*, Vol 3, pp. 427—435.
Piramuthu, S. (2005). Knowledge-based framework for automated dynamic supply chain configuration, *European Journal of Operational Research*, Vol. 165, pp. 219–230.

Puigjaner, L. (2008). Capturing dynamics in integrated supply chain management, *Comput Chem Eng*, Vol. 32, No. 11, pp. 2582-2605.

Sadeh, N, Hildum, D W, Kjenstad, D and Tseng, A. (1999). MASCOT: An Agent-Based Architecture for Coordinated Mixed-Initiative Supply Chain Planning and Scheduling, *Third International Conference on Autonomous Agents (Agents '99) Workshop on Agent-Based Decision Support for Managing the Internet-Enabled Supply Chain*, Seattle WA.

Shaohua, L. (2008). Research on Supply Chain Risks Management by Simulation Analysis, *Proceedings of the 7th International Conference on Innovation & Management*.

Shen, W. and Norrie, D.H. (1998). An Agent-Based Approach for Distributed Manufacturing and Supply Chain Management, in eds. Jacucci, G, *Globalization of Manufacturing in the Digital Communications Era of the 21st Century: Innovation, Agility and the Virtual Enterprise*, Kluwer Academic Publisher, pp. 579-590.

Singh, M and Raisinghani, M. (2001). Data Mining for Supply Chain Management in Complex Networks: Concepts, Methodology and Application, in eds. Becker, S, *Developing Quality Complex Database Systems: Practices, Techniques and Technologies*.

Stadtler, H and Kilger, K. (2008). Supply Chain Management and Advanced Planning, 4th Edition, 2008 Springer-Verlag Berlin Heidelberg.

Supply Chain Council. (2008). SCOR booklet, version 9.0, Available at: http://supply-chain.org/resources/scor.

Tah J H M and Carr, V. (2001). Towards a framework for project risk knowledge management in the construction supply chain, *Advances in Engineering Software*, Vol. 32, pp. 835-846.

Thotappa, C and Ravindranath, K. (2010). Data mining Aided Proficient Approach for Optimal Inventory Control in Supply Chain Management, *Proceedings of the World Congress on Engineering 2010*, Vol I.

You, F, Wassick, J M and Grossmann, I E. (2009). Risk Management for a global supply chain planning under uncertainty: Models and Algorithms, *AIChE Journal*, Vol. 55, No. 4, pp. 931–946.

Verdicchio, M and Colombetti, M. (2002). Commitments for Agent-Based Supply Chain Management, *ACM SIGecom Exchanges*, Vol. 3, No. 1.

Wooldridge, M. (1999). Intelligent Agents, in eds. Weiss, G, *Multiagent Systems: A Modern Approach to Distributed Artificial Intelligence.* The MIT Press, pp. 27-77.

Wooldrige, M and Jennings N. (2005). Intelligent Agents: Theory and Practice, *Knowledge Engineering Review*, Vol. 10, pp. 115-152

Wu, J, Ulieru, M, Cobzaru, M and Norrie, D. (2000). Supply chain management systems: state of the art and vision, *9th International Conference on Management of Innovation and Technology,* IEEE.

Xia, D and Chen, B. (2011). A comprehensive decision-making model for risk management of supply chain, *Expert Systems with Applications*, Vol. 38, pp. 4957–4966.

Zambonelli, F, Jennings, N and Wooldrige, M. (2000). Organisational Abstractions for the Analysis and Design of Multi-Agent Systems, *Workshop on Agent Oriented Software Engineering ICSE.*

Zarandi, M H F and Zarandi, M M F. (2008). Fuzzy Multiple Agent Decision Support Systems for Supply Chain Management in eds. Vedran Kordic, *Supply Chain,Theory and Applications*, pp. 558, I-Tech Austria.

Zeng, D D and Sycara, K P. (1999). Agent-Facilitated Real-Time Flexible Supply Chain Structuring, *Proceedings of the 1999 Autonomous Agents Workshop on Agent Based Decision Support for Managing the Internet Enabled Supply Chain*, pp. 21-28.

Zsidisin, G A. (2003). Managerial Perceptions of Supply Risk, *Journal of Supply Chain Management*, Vol. (39), pp. 14-25.

Zhong, N N, Lan, H and Wang X. (2002). CIMS Integrated Scheme Introduced with Data Mining and Supply Chain Management, *International Conference on Systems, Development and Self-organization.*